ANALYSIS OF HUNGARIAN SILVER COINAGE OF THE 11TH-13TH CENTURIES, KEPT IN THE NATIONAL MUSEUM OF SLOVENIA

A SZLOVÉN NEMZETI MÚZEUM 11–13. SZÁZADI MAGYAR EZÜSTÉRMÉINEK VIZSGÁLATA •

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Abstract

A series of 24 Hungarian silver coins dated between the 11th and 13th century kept in the National Museum of Slovenia was analyzed by the method of PIXE using in-air proton beam. The analysis showed that most of the coins were made of high-quality silver except for the coins of anonymous issues during the 12th century. The analysis did not detect degradation during the period of Mongolic attacks in the mid-13th century, which points to the strict monetary politics of Béla IV, contrary to the issues in debased metal during the previous century. The analysis also did not detect silver marked with high levels of bismuth that might have reached Hungary from the west, but the slightly increased bismuth levels in certain coins suggested that this type of silver was diluted with silver from other sources. According to the admixture of gold, the silver metal was principally obtained from cerussite and oxidized ores.

Kivonat

A Szlovén Nemzeti Múzeum 24 példányból álló, 11–13. századi magyar ezüstérme gyűjteményét kivezetett protonnyalábos PIXE módszerrel vizsgáltuk. Kimutattuk, hogy az érmék többsége kiváló minőségű ezüstből készült, csupán néhány 12. századra datált, nem azonosítható példány bizonyult eltérő összetételűnek. A vizsgált leletegyüttes alapján a 13. század közepén nem mutatható ki a tatárjáráshoz köthető értékromlás, ami jelzi – a 12. századi csökkent értékű érmeösszetételekhez képesti – a IV. Béla uralkodása alatt fennálló stabil gazdasági helyzetet. A Magyar Királyságba ez idő tájt nyugat felől érkező, bizmuttartalmú ezüstöt nem azonosítottunk, azonban a több érmében érzékelhető, kismértékű bizmutdúsulás jelezheti a nyugati és más eredetű ezüstércek szándékos ötvözését. Az érmék aranytartalma az ezüst cerusszitos és más oxidos érc eredetre utal.

KEYWORDS: MEDIEVAL SILVER COINS, HUNGARY, PIXE

KULCSSZAVAK: KÖZÉPKORI EZÜSTÉRMÉK, MAGYARORSZÁG, PIXE

Introduction

The numismatic cabinet of the National Museum of Slovenia also keeps a series of Hungarian medieval silver coins. This enabled us to study their composition from the early issues on, yet for practical reasons and historical arguments we limited our study to the first three centuries, i.e. from the 11th to the 13th century. The main historical boundary in the 13th century is invasion of Mongols, who in 1241 inflicted a devastating defeat to the Hungarian knight army, led by their king Béla IV and his brother duke Coloman (Kálmán).

The defeat annihilated the armed forces, and the following raids caused numerous victims among the civilians.

Between 50 to 80 percent of the settlements were destroyed in the plains, and about 20–35 percent of population was lost in the woodlands (Makkai 1994a). According to a more conservative estimate, the total loss of population was between 15–25% (Laszlovszky 2018). We were interested in whether such fatal events were also reflected in the quality of contemporary coin issues.

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Fig. 1a: The analysed coins kept in the Numismatic Cabinet of the National Museum of Slovenia. The numbers as in **Table 1.**

1a ábra: A Szlovén Nemzeti Múzeum Numizmatikai Gyűjteményéből elemzett érmék. A számozás feloldása az **1. táblázat**ban.

Fig. 1b: The analysed coins kept in the Numismatic Cabinet of the National Museum of Slovenia. The numbers as in **Table 1.**

1b ábra: A Szlovén Nemzeti Múzeum Numizmatikai Gyűjteményéből elemzett érmék. A számozás feloldása az **1. táblázat**ban.

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Our second motivation was based on our earlier study of the medieval silver coinage on the territory of the present-day Slovenia and the neighboring countries (Šmit & Šemrov 2006). In this study we characterized the quality of silver by predominant gold or bismuth impurities. Coins marked with bismuth concentrations up to 1.2 mass% were identified in the mints of Carinthia in Austria and in the mints on the Slovenian eastern border. The activity of these mints vanquished in the 13th century. We assumed that the Carinthian silver was traded to the eastern mints, which further supplied silver to the Hungarian kingdom on the east. The events of the 13th century, besides the Mongolian invasion also the ascendancy of Habsburgs, reduced the supply of silver to the east and thus caused the eastern mints to decline. The most current currency then became the Viennese pfennig. We were thus interested if the bismuth-primed silver can be traced in the Hungarian silver coins as well.

For comparison with our data, we used a comprehensive set of measurements of (Rácz et al. 2013) executed by X-ray fluorescence, though these data include a different set of elements and extend over a broader historical range up to the 15th century.

Methods

The analysis involved 24 coins (**Table 1.** and **Fig. 1.**) extending from the first Hungarian king István I (997–1038) to Béla IV (1235–1272) (Huszár 1979). For our study we distributed the coins into 5 specific groups: coins of the 11th century (István I and László I), coins of the 12th century (Kálmán I, Béla II and Béla III), anonymous coinage of the 12th century, coins of the 13th century (among them we included three bracteates that can be ascribed either to Béla III or Béla IV), while the fifth group included Slavonic banal denars from the king István V to Gutkeled Joakim. Beside the three bracteates and one obolus (András II), all coins were denars.

The coins were in different states of patination. For the measurement we selected the cleanest part of the coin, which was washed with alcohol. Measurements were taken on both sides of the coin, and the mean value of the results was calculated.

The analytical technique was in-air PIXE, which is frequently used for the analysis of historical silver coins (Daccà et al. 2000, Flament & Marchetti 2004, Rautray et. al 2011, Beck et al. 2017). The analytical procedures were applied at the Tandetron accelerator of the Jožef Stefan Institute in Ljubljana. The beam of 3 MeV nominal energy entered air through a Si_3N_4 window of 200 nm thickness. After passing about 1 cm air gap, the energy on the target was about 2.91 MeV. The proton current was a few tenths of nA and the measurements in particular point lasted about 500 seconds. The induced X-rays were detected by a Si(Li) detector of 140 eV resolution at 5.89 keV. The detector was positioned at 45º with respect to the target surface normal and 4.5 cm from the target. The detector was equipped with an aluminium absorber of 0.1 mm thickness; another absorber was an ice layer on the detector crystal which we presently estimate to 0.0025 g/cm^2. The X-ray spectra were fitted by the Xantho code (Šmit 2023), while the elemental concentrations were calculated according to the code presented in (Šmit et al. 2005), with an assumption that the mass percentages of individual elements sum to 100%. The accuracy of major concentrations was estimated to be within ±5% and those of minor concentrations within ±10%. The uncertainties are also larger for Zn in the presence of strong copper lines, as Zn Kα line is superimposed on the low-energy tail of Cu Kβ line. This also implied the detection limit for zinc about 0.05 mass%. The detection limits for other minor elements were 10 μg/g for Ni and 50 μg/g for Fe and the L-lines based elements (Au, Pb, Bi). The detection limits for the elements heavier than silver (Sn, Sb) were 100 μg/g.

As the effects of silver surface enrichment are known, it is necessary to check the measurements by a method that is bulk sensitive. Here we chose a simple density measurement, but which also represented a challenge as several coins have mass below 0.2 g. For the first attempt we chose the heaviest coins and performed weighting with a handy digital scale with a precision of 0.01 g. For determining the density of a bracteate that only weighted 0.18 g, we applied a scale with a precision of 0.001 g and designed a special hook for immersing the coin into water. The optimal solution was a hook of silvered copper wire of 0.2 mm thickness. The silvered surface eliminated the surface tension effects, while the known dimensions of the wire allowed to include the volume correction of the immersed part of the wire numerically. The density at the silver level (10.5 g/cm^3) was then measured with an accuracy of 0.4 g/cm^3.

Results

The analytical results are given in **Table 1.**; beside silver and copper, the trace elements detected were nickel, zinc, tin, antimony, gold and bismuth, while iron may be surface impurity from the earth or from the iron die. At one coin (anonymous of the 12th c.), a variable mercury content was also detected, signifying surface silvering.

The silver content for the coins, arranged in decreasing silver content, are shown on **Fig. 2**.

Table 1.: Elemental concentrations in mass%. Dashes (-) denote the element was not detected. The colour scale denotes distribution into specific groups: 11th century (yellow, 1-2), 12th century (dark blue, 3-6), anonymous coinage of the 12th century (light blue, 7-13), 13th century (red, 14-18) and Slavonic bans of the 13th century (magenta, 19-24).

1. táblázat: Elemi összetétel adatok tömeg%-ban megadva. A nem kimutatott elemeket negatív jel (-) jelöli. Színkód: 11. sz. (sárga, 1-2), 12. sz. (sötétkék, 3-6), 12. sz.-i ismeretlen eredetű (világoskék, 7-13), 13. sz. (piros, 14-18) és 13. sz.-i szlavón bánsági (magenta, 19-24).

No.	Cat.No.		Fe	Ni	Cu	Zn	Au	Hg	Pb	Bi	Ag	Sn	Sb
1	45087	István I (997–1038)	0.22	-	2.9	0.04	0.12	-	0.56	0.04	96.2	-	-
2	45088	László I (1077–1095)	0.03	-	10.3	0.06	0.36	-	0.21	0.04	89.0	-	-
3	76289	Kálmán (1095–1116)	0.04	-	1.7	0.06	1.09	-	0.43	0.06	95.9	0.7	-
4	76293	Béla II (1131–1141)	0.06	-	16.2	0.25	1.18	-	0.54	0.02	81.7	-	-
5	14080	"	0.09	0.052	19.4	0.39	1.23	-	0.83	0.05	77.4	0.66	-
6	76288	Béla III (1172–1196)	0.13	0.012	6.49	0.04	0.56	-	0.83	0.15	91.8	-	-
7	51730	Anonymous 12th c.	0.04	-	5.49	0.13	1.78	-	0.68	0.04	91.4	0.45	-
8	45089	"	0.04	-	21.3	-	1.34	-	1.06	0.08	76.2	-	0.07
9	76292	"	0.04	-	49.3	-	0.77	-	1.67	0.07	48.1	-	0.07
10	51731	"	0.11	-	59.0	-	0.75	-	1.48	0.12	38.6	-	-
11	76287	"	1.31	-	91.5	-	0.45	0.23	0.78	0.03	5.44	-	0.26
12	51729	"	0.08	-	74.5	-	0.37	-	0.64	0.1	24.2	-	0.16
13	204173	"	0.86	-	72.0	0.40	1.53	-	0.85	0.01	24.2	-	0.23
14	204172	Béla III (1172–1196)-Béla IV (1235–1270)	0.02	-	2.24	-	0.11	-	0.25	0.01	97.4	-	-
15	76291	"	0.03	-	4.92	-	0.52	-	0.81	0.19	93.6	-	-
16	14081	"	0.02	-	8.17	-	0.51	-	0.17	-	91.1	-	-
17	51728	András II (1205–1235)	0.03	-	1.55	-	0.82	-	0.41	0.1	97.1	-	-
18	16087	Béla IV (1235–1270)	0.06	-	1.47	-	0.89	-	0.23	-	97.4	-	-
19	50858	Slavonic bans (1270–1272)	0.03	-	3.15	-	0.67	-	0.31	0.07	95.8	-	-
20	50855	"	0.03	-	5.11	-	0.27	-	0.36	0.14	94.1	-	-
21	79172	"	0.05	-	10.3	-	0.78	-	1.29	0.14	87.2	-	0.21
22	79173	"	0.02	-	8.98	-	0.87	-	0.3	0.03	89.8	-	0.04
23	26889	"	0.02	0.021	3.03	-	0.24	-	0.34	0.07	96.3	-	0.04
24	88323	"	0.02	-	1.48	-	0.32	-	0.13	0.05	98.0	-	-

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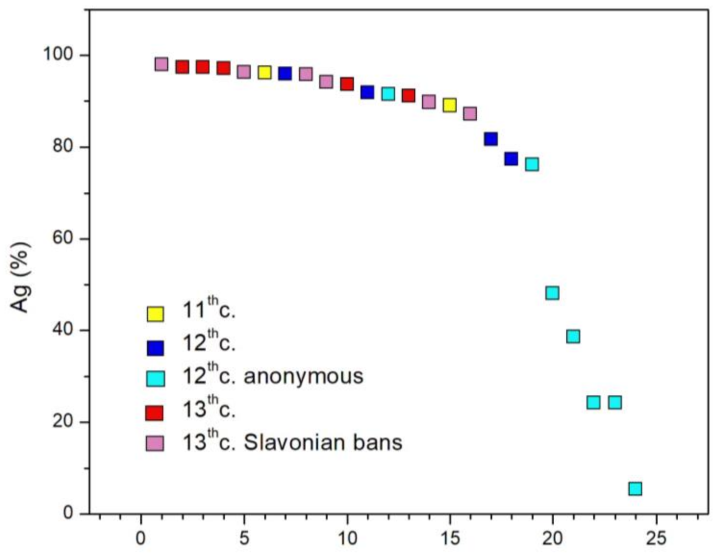

Fig. 2.:
Silver content (mass%) in the coins, re-arranged in decreasing silver concentrations
2. ábra:
Az érmék ezüsttartalma (tömeg%), csökkenő koncentrációérték szerint rendezve

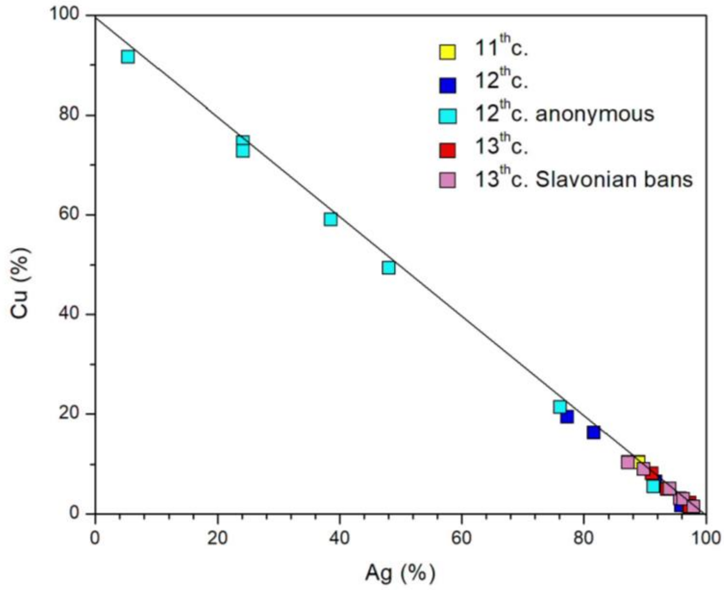

Fig. 3.:
Copper content (mass%) in the coins as a function of the silver content. The solid line corresponds to the binary copper-silver alloy.
3. ábra:
Az érmék réz- és ezüsttartalmának (tömeg%) viszonya. Az egyenes a réz-ezüst kétfázisú rendszert jelöli.

We can see that most coins are made of high-quality silver, exceeding 90 mass% Ag. Markedly different are coins of the 12th century, namely two coins with king names (while two are among the high-Ag group) and all anonymous issues. In the study of (Rácz et al. 2013), a compositional difference was detected before and after the reign of András II (1205-1235). We comment that this difference reflects the occurrence of low-grade coins during the 12th century.

In **Fig. 3.**, a relation between copper and silver is shown. One can easily observe that all measured points lay on a straight line, characteristic for the binary copper-silver alloy. The density measurements for the heaviest two coins (László I and Béla IV) showed the densities of 10.1 ± 0.5 g/cm^3 and 10.4 ± 0.5 g/cm^3. For the lighter bracteate of Béla III/Béla IV, a measurement with a more precise scale gave 10.4 ±0.4 g/cm^3. These three values confirm that the high-silver values measured at the surface extend into the bulk region. This is not obvious, as silver enrichment of the surface could have been present (Beck et al. 2004, Beck et al. 2008, Hrnjić et al. 2020). Small Celtic silver coins from Slovenia, showing uniform silver content on the surface, in total contain much less silver, pointing to a two-head distribution (Šmit et al. 2020). Medieval coins may even be made by hammering together brass and silver foils (Trela et al. 2025). Surface enrichment is less prominent at high-grade silver, besides several trace elements, such as gold, bind to silver; these effects were exploited in the study of small silver coins from the classical Greece (Šmit &Šemrov 2018).

As for the bracteate coin it is also tempting to compare the measured density to the silver content, as calculated from the semi-empirical relation that connects the alloy density with silver percentage in binary and ternary alloys (Kraut & Stern 2000). The density of 10.4 g/cm^3 corresponds to 94 mass% Ag in the silver-copper alloy, which is close to our surface values.

Discussion

Further properties of the coins were studied from the admixtures of traces elements, notably bismuth and gold.

As several coins (of the 12th century) contain lesser quantities of silver, we normalized the contents of Au and Bi with respect to that of silver; for low Au and Bi concentrations, these ratios correspond to mass percentages in the bulk silver. **Fig. 4.** shows that Bi/Ag ratios are smaller than 0.2%, and Au/Ag ratios smaller than 1%. Marked exceptions are again coins of the 12th century. Bi/Ag ratios for three coins are between 0.3 and 0.6%, while Au/Ag ratios exceed 1%, with the maximum values for two anonymous coins between 6 and 8%; however, these two high values are consequence of normalization to very low silver concentrations.

For further comparison with the silver coins from Slovenian mints we rely on the plots of kernel density estimate (KDE) (Šmit &Šemrov 2006). The results are shown in **Fig. 5**. The Hungarian coins peak at around 0.1% Bi/Ag, with a small contribution towards 0.2%, while the values above this value correspond to the three coins that excel in **Fig. 4.** as well. On the other hand, the mints from the territory of the present-day Slovenia can reach higher values, up to 1.2 mass% Bi (these values were not normalized to the silver content as it normally exceeded 85 mass%, Šmit & Šemrov 2006). These results suggest that the Bi-marked silver was used in Hungarian coins on a rather small scale and was probably diluted by silver from other sources. In a much larger set of data that involves coins up to the 15th century (Rácz et al. 2013), 38 coins out of 304 exceed the level of 0.2 mass% Sb (a fraction of 12.5%), and only six (2%) are in the range of 0.5–0.97 mass% Sb.

The gold content may to some extent reveal the source or the type of silver ore. In Antiquity and Middle Ages, silver was mainly extracted from lead-silver ores by the method of cupellation, which is based on the oxidation of metal silver until more noble silver remains.

In the study of (Wood et al. 2017), the distinction between the silver obtained from galena (PbS) or cerussite $PbCO_3$ (including oxidized ore) was determined from the gold and iridium concentrations. Though the study was based on Byzantine and Sassanian silver, the results can be deduced to our study as well; however, we can only rely on the gold values as the low levels of iridium are undeterminable by X-ray methods. The critical value is 0.1 mass% Au – concentration below this level signify galena as silver source, higher gold concentrations are significant for cerussite or oxidized ore.

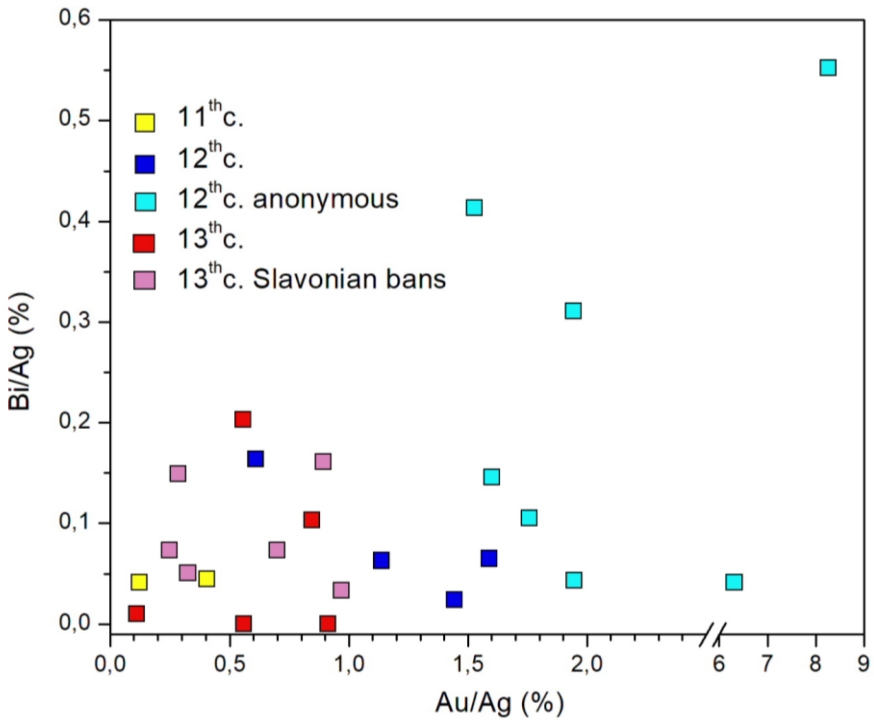

Fig. 4.:
Relative bismuth and gold concentrations, normalized to the percentage of silver

4. ábra:
Relatív bizmut- és aranytartalom, az ezüsttartalomra normálva

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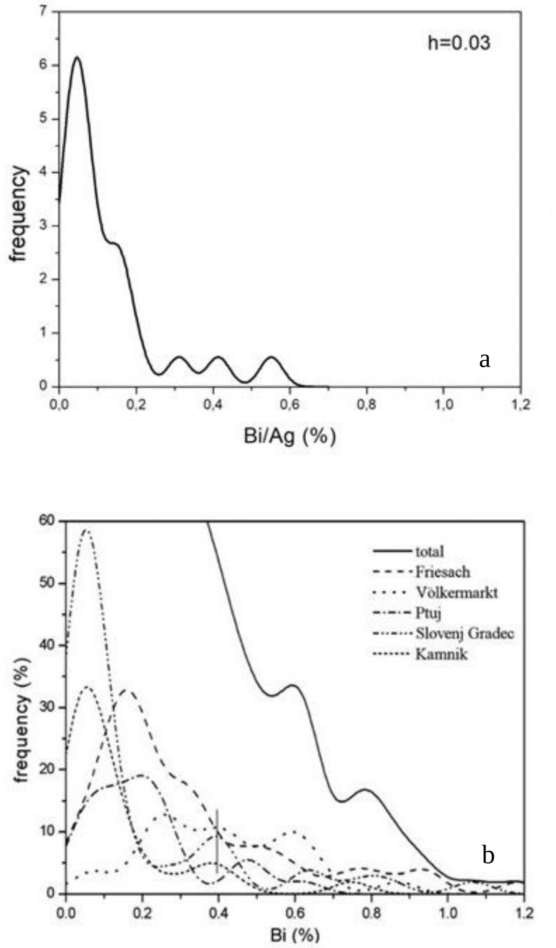

Fig. 5.: Kernel-density-estimate for the bismuth content. **a** – Hungarian coins; **b** – coins from the selected mints given in (Šmit & Šemrov 2006).

5. ábra: A bizmuttartalom magfüggvényes sűrűségbecslése (kernel density estimate, KDE) **a** – magyar ezüstérmékre és **b** – ismert verdék érméire (Šmit & Šemrov 2006).

Fig. 6. shows comparison of KDE for gold in Hungarian coins and the contemporary coins from the mints given in (Šmit & Šemrov 2006). In this case we calculated KDE for the Au/Ag ratio and the net Au content. Both distributions are similar, the difference is for the high-Au side. The distributions seem to be two-fold, suggesting two distinct silver sources.

Absolute Au concentrations extend up to 2 mass%, which is higher than for the mints in (Šmit & Šemrov 2006). It is easily observable that the fraction of the coins with less than 0.1 mass% Au is negligible (only two coins slightly exceed this limit), which excludes galena as an important source of metal silver.

The quality of the cupellation procedure is studied in the binary diagram (**Fig. 7.**) which shows the ratio of Pb/Ag with respect to Au/Ag. **Fig. 7.** shows approximate linear correlation. The values of Pb/Ag

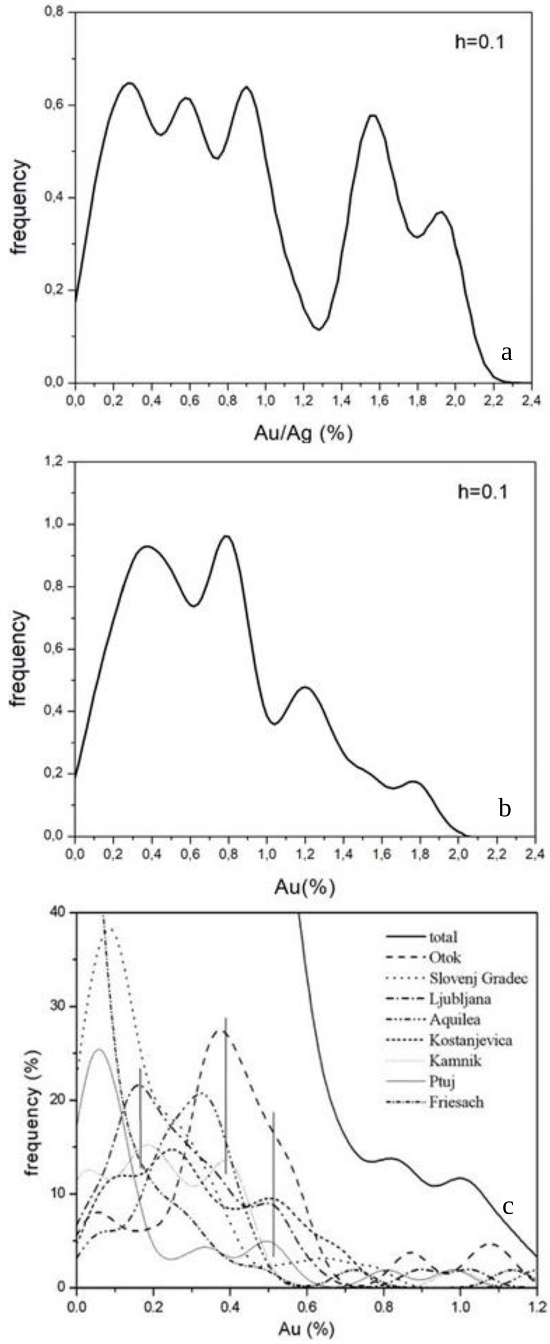

Fig. 6.: Kernel density for the gold content. **a** – relative gold content (with respect to Ag) for Hungarian coins; **b** – absolute gold content for Hungarian coins; **c** – absolute gold content for the mints in (Šmit & Šemrov 2006).

6. ábra: Az aranytartalom magfüggvényes sűrűségbecslése (KDE) **a** – magyar ezüstérmék relatív aranykoncentrációjára, **b** – magyar ezüst-érmék abszolút aranykoncentrációjára és **c** – ismert verdék érméinek abszolút aranykoncentrációjára (Šmit & Šemrov 2006)

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above 1.5% up to 15% are again characteristic of the anonymous coins of the 12th century. We may guess that the highest lead concentrations were not consequence of ineffective cupellation process, but lead was added intentionally to dilute the much more costly silver.

Coins of the 11th–12th century contain detectable amounts of zinc, with the highest values for the two coins of Béla II and two anonymous coins of the 12th century. Zinc may denote the presence of brass in the alloying copper.

Coins of the 12th century further contain small admixtures of tin and antimony. **Figs. 8** and **9** show the concentrations of both elements as a function of silver content. It is interesting to note that the higher content of tin (around 0.6 mass%) appears in two coins with names and in one anonymous coin (the only one with a high Ag content). Higher tin concentrations are then characteristic for the coins of high silver concentration. The reason for this is unknown. High tin concentrations were observed in small Celtic coins (Šmit & Kos 1984) and in Roman *victoriati* (Laharnar et al. 2017); the reason for the former was probably alloying silver with bronze instead of pure copper, while for the latter it was diluting of silver with cheaper tin. We may conjecture that the employment of bronze was also the source of tin in our case. An opposite behavior is observed for antimony. In this case the highest antimony concentrations (up to 0.25 mass%) are observed in the coins with the lowest silver concentrations. We expect that antimony in this case was admixture of the added lead, probably not so much from the ore, but likely by using the metal from some lead objects, which were made harder by addition of antimony.

At last, we check if the distinction of the 12th century coins can be stated as a collective property. For this we employ the methods of principal component analysis (PCA), and, since our five groups were pre-selected, the method of linear discrimination (LDA), using the concentrations of Sn, Sb, Au, Pb and Bi. **Fig. 10.** (for PCA) confirms that the coins of the 12th century (except for one coin with a name and two anonymous ones) form a separate group, located at the right side of **Fig. 10**. Among them is also one coin of the Slavonic bans. LDA (**Fig. 11.**) shows a similar result: while most of the coins with a high silver content are closely grouped, there is a diffuse group on the right side of **Fig.11.** that contains all 12th c. anonymous coins and the already mentioned coin of the Slavonian bans (no. 21). The reason for its position is relatively high concentrations of lead (1.29 mass%) and antimony (0.21 mass%). The two coins with names of the 12th c. are located between the two groups.

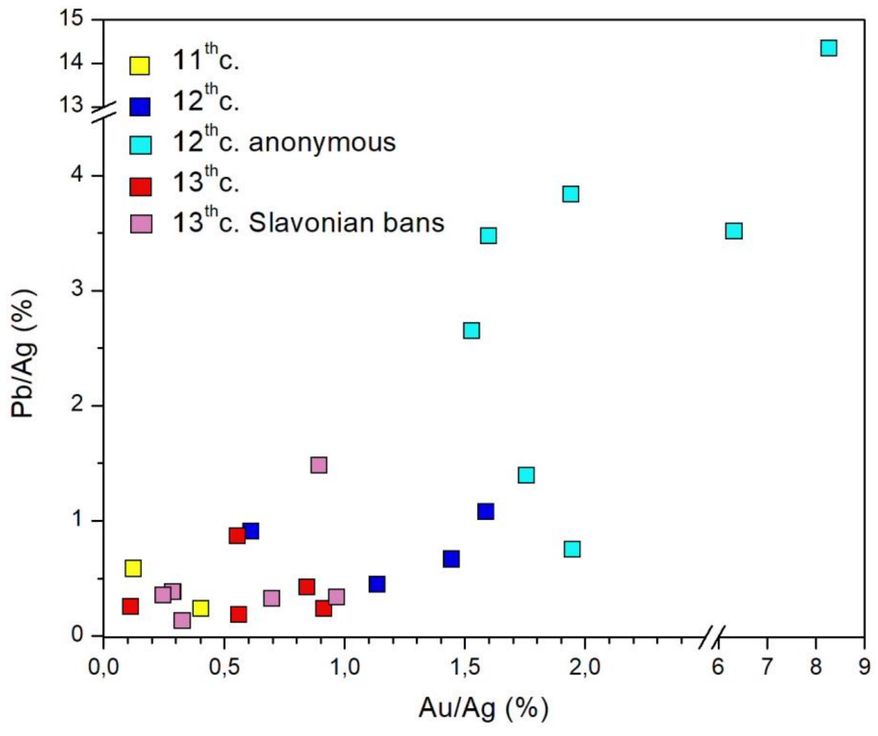

Fig. 7.:
Relative lead content as a function of the relative gold content

7. ábra:
Relatív ólom- és aranytartalom az ezüstkoncentrációhoz viszonyítva

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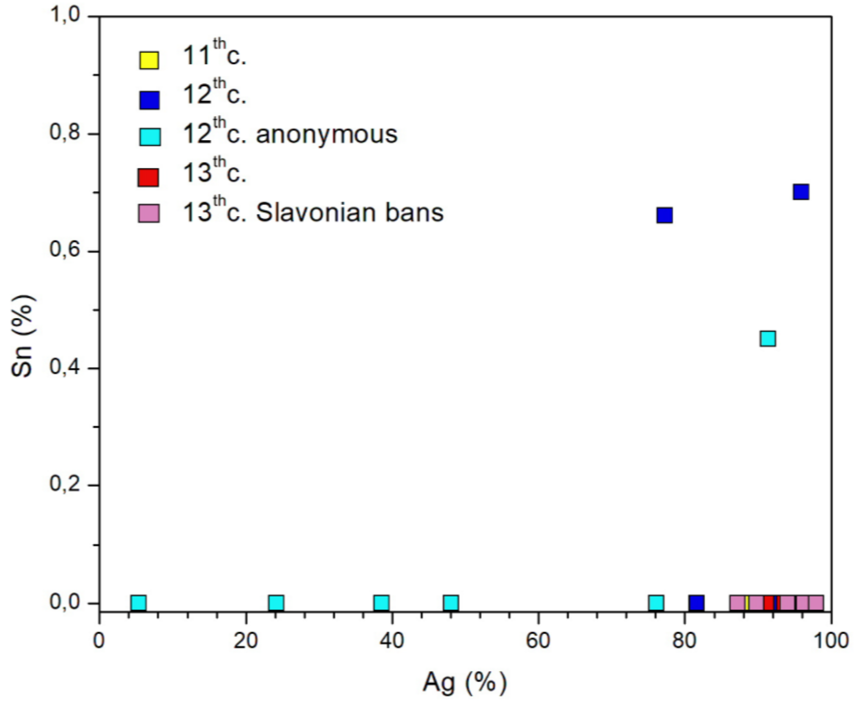

Fig. 8.:
Tin content (mass%) as a function of silver content (mass%)

8. ábra:
Az érmék ón- és ezüstkoncentrációja (tömeg%)

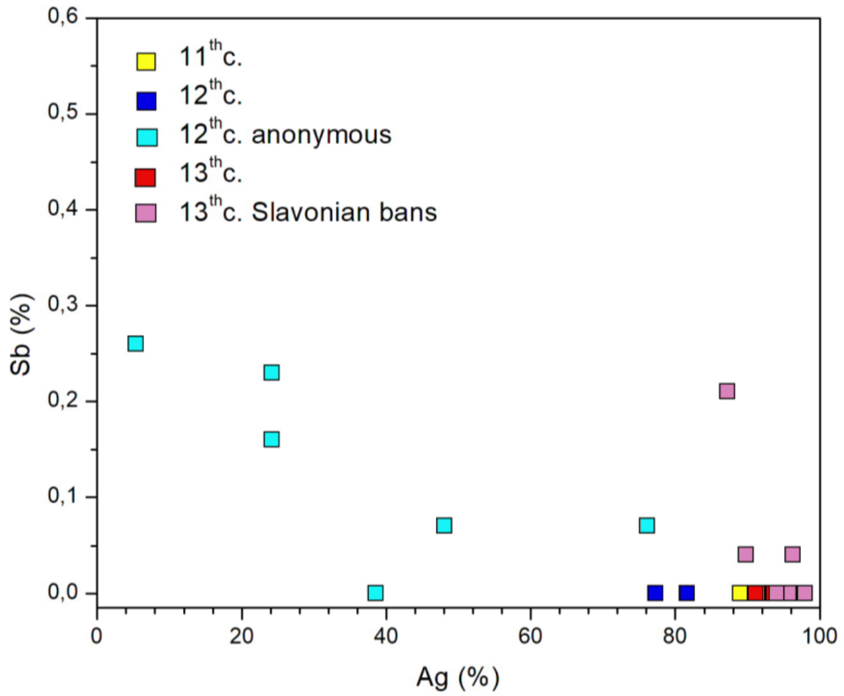

Fig. 9.:
Antimony content (mass%) as a function of silver content (mass%)

9. ábra:
Az érmék antimon- és ezüstkoncentrációja (tömeg%)

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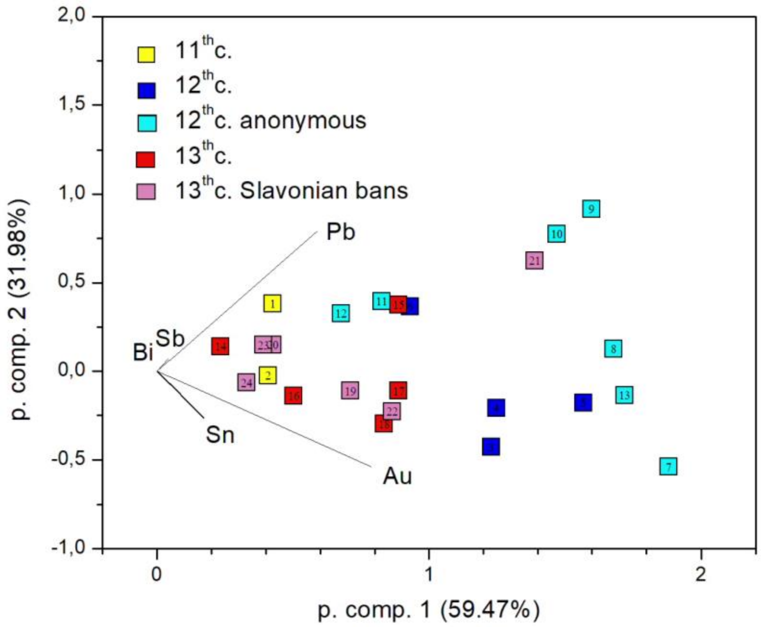

Fig. 10.: Principle-component analysis of the coins concerning the contents of Sn, Sb, Au, Pb and Bi. The first two components retain 91.45% of the total variation

10. ábra: Az érmék Sn, Sb, Au, Pb és Bi koncentráció-adatainak főkomponens analízise. Az első két komponens a változékonyság 91.45%-át fedi le.

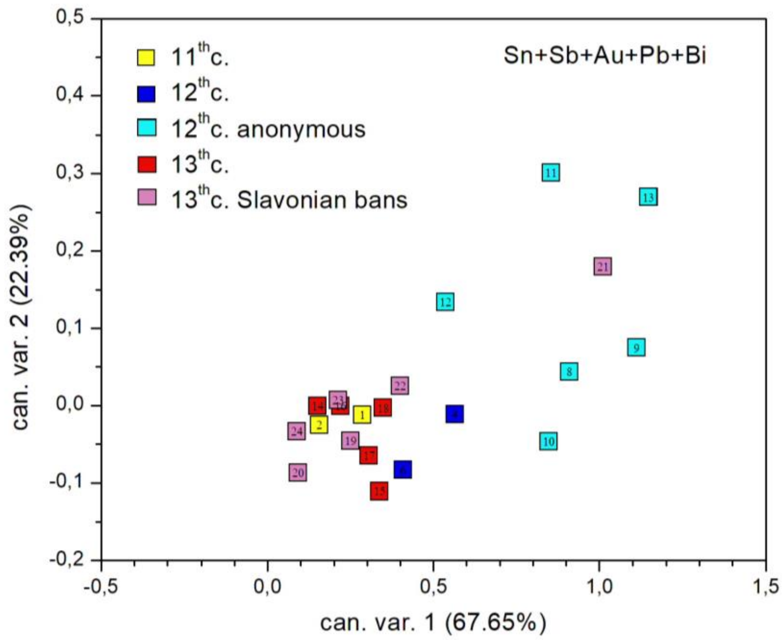

Fig. 11.: Linear discriminant analysis of the coins, concerning the contents of Sn, Sb, Au, Pb and Bi, and relying on the distribution of five distinct groups

11. ábra: Az érmék Sn, Sb, Au, Pb és Bi koncentráció-adatainak lineáris diszkriminancia analízise az öt régészeti csoport jelölésével

Conclusions

The analyzed coins belonging to the period of the 11th–13th century are produced of high-quality silver, with the silver content exceeding 90%. Exceptions are the coins of the 12th century, which are produced of low-quality silver, with a higher percentage of impurities of lead, tin and antimony. On one coin, the presence of mercury signifies silver plating with silver-amalgam or later processing with liquid mercury with an aim to improve the 'silver' look. This coin may be regarded as forgery.

There is no debasement in the 13th century, which confirms the stable monetary politics of Béla IV during the Mongolian attack. This complies with the explanation that several, mostly wooded western areas of Hungary remained unaffected by the invasion. The king, after a short flight to Dalmatia, was able to raise a military campaign for recapturing the territories of Friedrich II Babenberg of Austria just two years after the unexpected Mongol withdrawal in 1242 (Makkai 1994a).

The bismuth-primed silver was not directly detected. Three coins with an increased bismuth concentration do not meet the highest level of 1.2 mass% Sb detected in the coins minted beyond Hungarian western borders (Šmit &Šemrov 2006), so we may conclude that this type of silver was only traced in the recycled material, circulating during the 12th century. High gold concentrations above 0.1 mass% exclude exploitation of galena lead ore as a source of silver but point to cerussite or oxidized ore.

It is certainly challenging to discuss why the low-quality silver coins and forged coins did not appear during the politically and economically critical period, but during the century when the economy was prospering (Makkai 1994b). We may conjecture that the expanding economy was requiring large quantities of currency but there was simply not enough silver on the market, which was then characteristic for the whole continent (Laszlovszky 2021). This had stimulated anonymous issues of the coins, while the lust for profit fostered minting coins with fraudulently lower silver content.

Contribution of authors

Žiga Šmit Investigation – Formal analysis – Data curation – Writing – Original Draft, Review & Editing. **Andrej Šemrov** Resources – Writing – Original Draft, Review & Editing.

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